The Effects of Mining Subsidence on a Motorway Bridge

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SYNOPSIS: Mining subsidence causes ground movements which are imposed on any structure in the area of influence. Bridges are particularly susceptible to subsidence, which frequently causes damage and occasionally collapse. Special bridge designs have been developed to cater for mining subsidence. This paper provides details of the performance of such a structure subjected to significant ground strain.

INTRODUCTION

Mining subsidence is ground movement caused by mineral extraction. In many cases, the movement extends to the surface and is three dimensional in character. Any affected point within the zone of influence having components of displacement along all axes of a Cartesian coordinate system. These displacements are imposed on any structure in the affected zone and may cause damage or distress unless adequate safeguards are taken. Bridges are particularly susceptible to mining subsidence damage leading to the need to impose load restrictions or even causing total collapse.

In the past, buildings and structures were sufficiently small or flexible that the effects of mining subsidence could be tolerated or avoided by the sterilisation of appropriate areas from mining activity. Modern mining methods which use highly mechanised systems of extraction and which demand major capital investment, make sterilisation of coal under a particular area or bridge prohibitively expensive and inefficient. As a result it is necessary for bridge structures to be capable of withstanding ground strains resulting from the moving mining wave.

This paper provides a case history of a modern motorway bridge which has been subjected to severe mining subsidence. Details are given of the design of the bridge and of the mining together with the resulting ground strains and the performance of the structure. The management of the bridge during the mining phase is described and details of the remedial works and costs provided.

DESIGN OF BRIDGES IN AREAS OF MINING SUBSIDENCE

The majority of bridges built in the United Kingdom were constructed before the introduction of modern mining methods and no structural precautions were taken to cater for large differential ground movements. Little is known about the tolerance of bridges to movement. What is known is that certain structural forms are more susceptible to ground strain than others. Arch bridges are particularly at risk.

A valuable contribution to tolerance movement criteria in bridges has been provided by Moulton et al (1982) in a study undertaken on behalf of FHWA. Based upon a large number of observations, Moulton et al were able to establish tolerance limits for a number of movements including:

i. Angular distortion (differential settlement/span length)
   Continuous steel structures - 0.004
   Simply supported steel bridges - 0.005

ii. Horizontal movements of Abutments < 34mm

iii. Differential vertical settlement
   Simply supported bridges - no limit (within the range tested)
   Continuous bridges - total negative stress over supports < AASHTO (1975) Limiting stress criteria

The findings of Moulton et al confirm the observations in the United Kingdom that mining subsidence movements, in which settlements in excess of 1 metre and ground strains of upto 0.5 per cent are frequent, would normally result in overstress and damage to a conventional highway bridge.

The problem of mining subsidence was recognised in the United Kingdom at the start of the motorway building programme in the 1960's when the M1 London Yorkshire motorway was detailed to pass across the Derbyshire and Yorkshire coalfields.

Two main approaches to the design of bridges were developed to provide safeguards against the effects of subsidence. The bridges could be designed to be statically determinate, with stiff decks resting on a three point support system (similar to a three legged stool) or, alternatively made flexible being built up of a series of articulated parts and having low torsion decks capable of accommodating large angular rotations.

In the first design concept the bridge rides the subsidence wave and differential horizontal movements are accommodated with the use of anticlastic bearings. In the latter design technique the bridge is made capable of absorbing the mining movements as they occur without loss of load carrying capacity. Experience of the Yorkshire coalfield in the United Kingdom has shown that an average highway bridge of between one to four spans could be subjected to the following mining movements:

a. Differential longitudinal horizontal displacement ± 150-225mm
b. Differential transverse displacement ± 150mm
c. Differential vertical displacement 0.6-0.9m
d. Longitudinal angular distortion 1 in 80
e. Transverse angular distortion 1 in 150
f. Differential rotation in plan 0.3°

No bridge would be subjected to the full range of movements detailed above, but a major complication in design is that predicting which movements would occur is dependent on the geometry of the mining relative to the bridge. At the time of design this is unknown.

In the majority of cases in the Yorkshire coalfield, the flexible design approach was adopted. Minor damage to the structures was deemed acceptable and inevitable but the full use of the motorway had to be retained, except during post mining repairs. In addition it was important that the cost of bridges built to cater for mining subsidence should not be greater than the cost of a conventional bridge. In the systems developed in Yorkshire this latter condition was exceeded in that the low torsion decks developed for mining was adopted for general use even when mining was not expected, the reason being that the low torsion decks proved to be less costly than the conventional decks.

SHILLINGHILL BRIDGE

Shillinghill Bridge carries the M62 Lancashire Yorkshire motorway M62 over the A645 Pontefract-Knottingley road. The M62 crosses a railway embankment 200 metres to the north of the A645 and the difference in carriageway levels is in the order of 12 metres. The A645 has a carriageway width of 13 metres with two 2 metre footpaths. For both economic and asthetic reasons the bridge was designed as two identical parallel 3 span structures, one supporting the eastbound carriageway, the other the westbound.

Each deck consists of 12 standard prestressed concrete beams (type 75/D) 21 metres long and a 175mm reinforced concrete deck slab. The bridge skew is approximately 11°. The deck was analysed using load distribution methods with an allowance for edge beam stiffening.

The piers are reinforced concrete and were designed to take into account small but significant mining movements and a steeply sloping foundation. At the time of the design of the bridge in 1970, mining movements were predicted to be in the order of 1.5mm/metre but is was not known when these movements would occur. The piers were designed using a computer program, Sims, Jones and Bellamy (1972). It was assumed that the movements would be taken up in the laminated rubber bearings and the shear forces produced were included in the design of the piers and bank seats.

The expansion joints were provided with a movement capacity sufficient to accommodate the anticipated mining strain of 90mm over the length of the bridge. The rock strata on which the bridge was founded slopes steeply from south to north and the northern piers are approximately 7 metres higher than the southern ones. Further technical details associated with the design of the bridge are given in Table 1. The bridge was constructed during 1972-1973.

TABLE 1. Technical Details of Shillinghill Bridge

<u>Deck Details</u>		
Number of lanes	4 Eastbound	4 Westbound
Width of deck	17.4m	17.4m
Thickness of deck slab	175mm	175mm
Span	20.1m	20.1m
Number of spans	3	3
Dead weight of deck	266.5 KN/m	265.5 KN/m
Number of beams/span (75/d)	12	12
Shear rating of bearings	2.35KN/mm	2.35KN/mm
Thickness of bearings	75mm	75mm
<u>Pier Details</u>		
Height (average)	18.5m	18.5m
Width (top)	17.3m	17.3m
Base width	5.5m	5.5m
Base breadth	13.8m	13.8m
Base thickness	1m	1m
Permissible bearing stress	536.25KN/m^2	536.25KN/m^2

NOTE 25 per cent over stress permitted during HB loading

MINING SUBSIDENCE

Shillinghill Bridge was mined under in 1981. Details of the mining are shown in Table 2. Figures 1,2 and 3 give details of the panel layout relative to the bridge and also provide details of the predicted surface contours for the longitudinal and transverse strain and the subsidence, based upon the use of the empirical prediction method developed by the National Coal Board (1975).

TABLE 2. Details of Mining Subsidence at Shillinghill Bridge

Colliery: Prince of Wales, Pontefract			
Seam	Depth	Width of Panels	Extraction
Castleford 4 foot	245m	240m	1.45m
Subsidence		Panel 44's	Panel 45's
Vertical		0.15m	0.2m
Longitudinal strain		Negligible	Negligible
Transverse strain		+ 4mm/m	+ 4mm/m

The position of the bridge relative to panels 44's and 45's was not advantageous and the bridge was subjected to significant movements. The mining caused the east and west bound carriageways to move apart at the western end of the bridge by upto 100mm. The bridge settled differentially and the decks rotated in plan causing disruption of the expansion joints and resulting in the combined parapet and crash barrier to fail in tension. An illustration of the degree and complexity of the movement suffered by the bridge is shown in Figure 4. The movements included an angular distortion of one deck in excess of 1 in 70. Although the mining caused severe disruption to the vertical alignment of the motorway supported by the bridge which required the imposition of speed limits, at no time was the carrying capacity of the bridge reduced.

The allowable shear strain of the rubber bearings was exceeded during the mining phase. Maintenance procedures were undertaken to relieve and reposition the bearings during the mining. This was achieved by the use of hydraulically linked flat jacks positioned between the bearings which were used to raise the deck a nominal amount (2mm) sufficient to permit the distorted rubber bearings to jump back into position. These works were undertaken by West Yorkshire Bridge Engineers working on Sunday mornings when the bridge traffic was light. Repositioning of the bearings was undertaken on a number of occasions.

REMEDIAL WORKS

The damage to the motorway caused by the mining subsidence was substantial. In accordance with the Coal Mining (Subsidence) Act of Parliament 1957, the National Coal Board are required to meet the cost of the remedial works considered necessary to restore the highway to a condition fit for use. In the case of the motorway at Shillinghill Bridge, remedial works cost in excess of £1.0 m. The National Coal Board contribution to the repair of the bridge was £110,000.

The remedial works which were undertaken when the motorway alignment and drainage was reconstructed consisted in jacking the bridge decks to conform with the revised vertical alignment and to remove the angular distortion. Included in the works was the partial reconstruction of the bridge bank seats raising them to the new alignment, renewing all bearing plinths and replacing all bearings and expansion joints.

No problems were encountered in the remedial works other than that the force needed to jack the deck well clear of the bearings proved to be in excess of the dead weight of the deck. This was caused by the presence of polystyrene foam used to create the expansion joint between the ends of the deck and the bank seat. Although this material is weak in compression, polystyrene proved to be very strong in shear.

CONCLUSIONS

Shillinghill Bridge was one of the first motorway bridges which had been specifically designed to cater for mining subsidence to actually be subjected to mining. The movements caused by the mining demonstrated the three dimensional nature of subsidence and also illustrated the difficulties of predicting movements at the design stage. The movements far exceeded and were different in nature to those anticipated in 1970.

The bridge behaved very well during the subsidence and demonstrated the validity of the design concept developed to cater for bridges in mining areas. The success of the design was further strengthened by the fact that three adjacent arch bridges had to be demolished and totally rebuilt because of the mining subsidence. In addition, a nearby overhead sign gantry had to be dismantled during the mining, and three miles to the east of Shillinghill Bridge the decks of a bridge spanning the M62 motorway had to be removed and shortened by diamond saw. To the north the cantilever span of a small footbridge had to be raised out of position while the mining wave passed through the area.

Figure 1

Contours of Transverse Strain (mm/m)

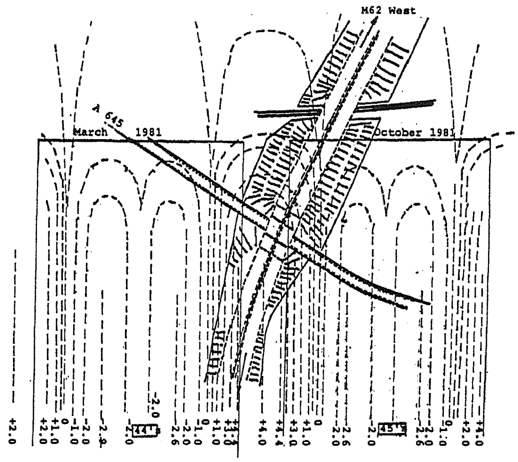


Figure 2

Contours of Vertical Settlement (Metres)

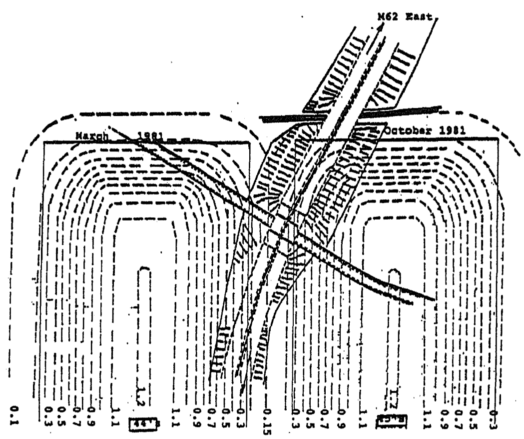


Figure 3

Contours of Longitudinal Strain (mm/m)

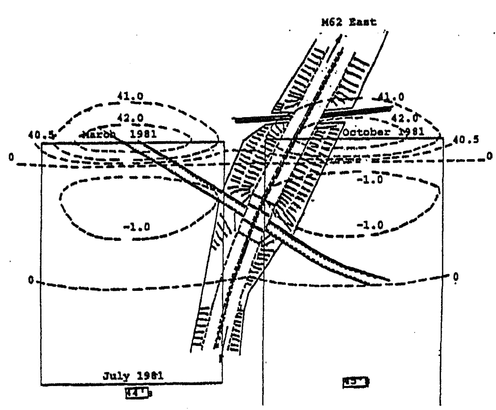
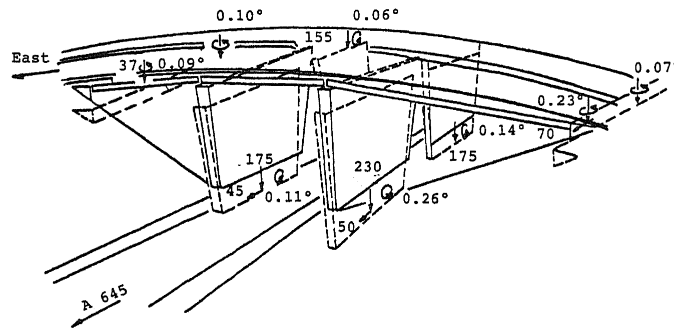


Figure 4

Shillinghill Bridge M62 Motorway

Mining Movements (mm) May 1981 - March 1982



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